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Developing a viable electric bus service: the Milton Keynes demonstration project

(Accepted Manuscript)

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ABSTRACT

Buses can be a serious source of city centre air pollution. Electric buses deliver zero emissions but, because of the time required to recharge, more buses are needed for a given timetable than diesel counterparts, so making mainstream electric bus operations prohibitively expensive.

Early 2014 saw the implementation in Milton Keynes of an electric bus service designed to overcome this problem. An entire bus route has been converted to electric operation with inductive charging at bus layover points. This permits the use of smaller and less expensive battery packs allowing the electric buses to operate continuously all day. This approach significantly reduces the cost of introducing a pure electric bus fleet.

This study not only provides an example of how the electric bus problem can be resolved technically. It also addresses the business structures required to deliver sustainable transport, introducing a different commercial model to that which is traditionally used for bus service delivery. This raises important points for regulatory and innovation policy. There is government support for sustainable transport technologies, but successful delivery in the commercial environment requires new institutional structures and business models as well. The Milton Keynes project has sought to develop such a structure.

1. The drive for low carbon buses

Despite the development of increasingly stringent emission standards, diesel buses remain a serious concern for air pollution in urban areas. This is why they have been included in initiatives such as the London Low Emission Zone (Ellison et al 2013), where emission of Nitrogen Oxides from diesel vehicles remains a persistent concern (McGrath 2014). The use of cleaner CNG and LPG-powered buses has found favour in a number of European states and is seeing growing use in China. Concerns over emissions from city buses have been reflected in local transport policy debate and discussion; for example, in Oxford, buses are considered to be a key contributor in making the city centre street of St Aldate's the ninth most polluted street in the UK (Airs, 2013).

Although engine and cleaner fuel technologies can be employed to mitigate air quality issues, increasingly stringent carbon reduction targets require a shift towards fuels that can be largely

decarbonised. In the UK, the *King Report* (King 2007) was a crucial turning point in policies for vehicle and fuel technologies to decarbonise road transport. For cars, this report concluded that hydrogen and biofuels would not deliver the rapid decarbonisation required. This led to a revision of policies to focus upon battery electric and hybrid technologies for the short-medium term. A government-industry strategy emerged over the next two years epitomised by the 2009 *NAIGT Report* on the future of the automotive industry (NAIGT, 2009). This set out a technology development 'roadmap' anticipating cleaner internal combustion technologies followed by uptake of battery electric and plug-in hybrid vehicles and then, much later, joined by hydrogen fuel cell vehicles.

There are valid issues concerning carbon emitted in generating electricity and in the manufacture of hydrogen, but unlike fossil fuels, production of electricity and hydrogen has the potential to be substantially decarbonised. A similar policy process has unfolded in a number of other European countries in the last decade, with support measures put in place for battery electric vehicles and public recharging infrastructure.

In the UK, the *Low CO₂ Technology Roadmap for Buses* (Atkins et al, 2013) applies to the bus sector the same approach as in the NAIGT report. This report identifies a series of lower carbon technologies, from those delivering a marginal reduction in CO₂ compared to a diesel bus, through to ones with a substantial decarbonisation potential. Hybrid vehicles (e.g. as used presently in London and Oxford) produce a 20-40% reduction in 'well to wheel' CO₂, but the only technologies to offer a high enough decarbonisation potential to address the targets set in the 2008 Climate Change Act (a 40% cut by 2020 and an 80% CO₂ cut by 2050) are biomethane, renewably-sourced hydrogen or battery electric vehicles.

2. The challenge for a battery electric bus design

As with previous studies on low CO₂ vehicle technologies, the *Roadmap for Buses* report noted the pattern of a higher capital cost which is counterbalanced by lower fuel and other operating costs. Battery-electric vehicles cost about twice that of their diesel equivalent, with the cost of batteries responsible for most of the difference. There is a payback period before the high capital costs are recouped in lower operating costs. This means that, commercially, high distance applications represent the most viable market sectors for low carbon vehicles. Urban buses typically cover 60,000 – 100,000 kilometres per year (around 200-300 kilometres per working day) and so would appear to be a viable market sector for a low CO₂ technology like battery-electric traction. However, for a large road vehicle like a bus, range limitations and recharging times of battery packs mean that such high utilisation is very difficult to achieve. An electric bus will have covered little more than a half of its daily operational distance before a lengthy recharge is needed. The battery-electric buses that have been used in a number of cities thus tend to operate on short routes and often require a larger fleet to allow for additional downtime for recharging. For example, the electric buses operating the Coventry Park-and-Ride shuttle service requires two vehicles to operate the service, with a third electric bus on charge. This three for two replacement of



Figure 1. Small battery-electric bus on a short route in Amalfi town centre in Italy.

diesel buses substantially increases both the capital and operational costs involved (each bus typically requires two drivers for a normal working day).

The recently introduced use of BYD electric buses on two short central London routes has involved a different approach (Transport News Brief, 2013). Here, electric buses are used to enhance peak frequency, so they operate in the morning peak alongside the core diesel fleet, return to a depot to recharge ready for running in the evening peak and then go back to the depot again for an overnight charge. This pattern suits operating requirements, but such low utilisation means it is unlikely that the high capital cost of purchasing the buses can be offset by reduced fuel costs.

These examples illustrate why achieving an effective operational range for electric buses has been a central issue in a number of studies. For example, in looking for an application in Taiwan, Tzeng et al (2005) concluded that hybrid electric buses would be the most suitable of available technologies, but the best alternative would be a pure electric bus if it could provide an acceptable range.

The range issue has thus been an important component of the Mitsui Arup Sustainable Projects (MASP) research that has informed the Milton Keynes electric bus demonstration project. But crucially this has set the demanding goal of designing a battery-electric bus system that can not only technically match a diesel bus, but also match it economically. This is not for small electric buses, but for a medium-sized buses carrying 40-50 passengers in mainstream bus operations.

MASP first studied a variety of urban bus routes operating in some of the world's major cities. Data were taken from these routes to calculate the energy required to be stored by a pure electric bus in each case. These data sets covered a variety of buses and operating conditions and included routes in Sao Paulo in Brazil, Shenzhen in China, London and Milton Keynes in the UK and Warsaw in Poland.

By way of illustration, Figure 2 shows the bus route (No 675-L10) used for the Sao Paulo data gathering. This has a route length of 12 kilometres, carries an average of 56.7 passengers and operates over an elevation profile as shown in Figure 3.

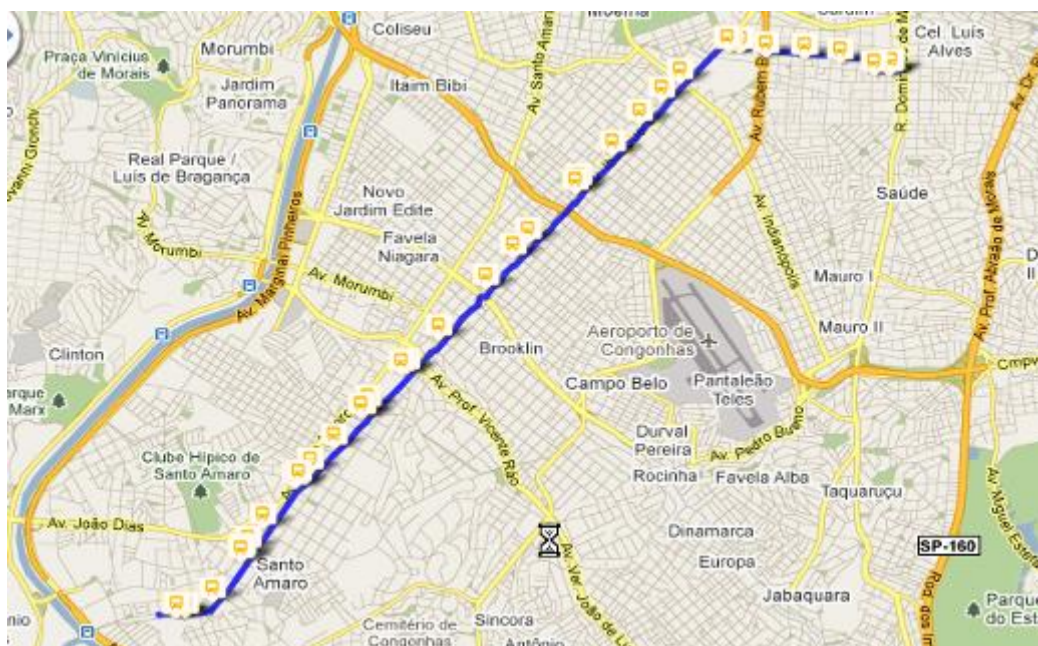


Figure 2. Map of Sao Paulo Route 675-L10

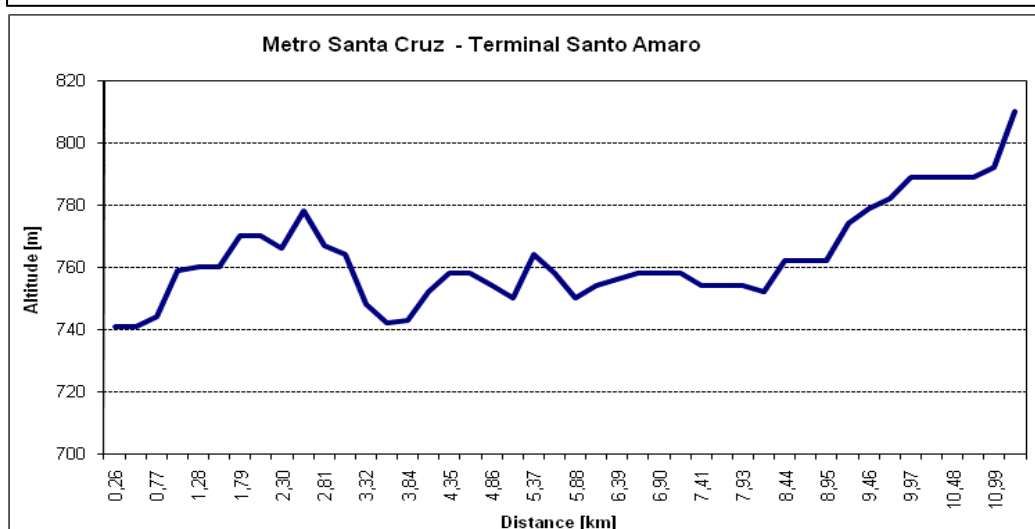


Figure 3. Elevation of Sao Paulo Route 675-L10

The London bus route used in the study was the 159 from Marble Arch to Streatham, which is a 10 minutes frequency service viewed as a typical, but demanding, pattern for operating conditions in London. This route achieved fame in 2005 for being the last route in London running the famous classic Routemaster bus. The Shenzhen route (No. 202) at 38 kilometres and with 93 bus stops, is longer than those in the other cities. The No 7 route in Milton Keynes is 24 kilometres long, one of the town's longest urban routes.

From these operational data it was possible to calculate the energy requirements for a full 16 – 18 hours working day and the battery size needed. The results are shown in Table 1.

CITY	BATTERY REQUIREMENT (kWh)
Sao Paolo	700
Shenzen	900
London	1000
Milton Keynes	500
Warsaw	650

Table 1. Battery requirements for electric bus routes

With EV battery packs costing around £500 per kWh (Element Energy, 2012), large battery packs represent a substantial cost item. Battery size is thus crucial to both technical performance and economic viability. The Milton Keynes case of a medium-length route and relatively low frequency (15 minutes) produced the lowest power requirement, but even then it needed 5 tonnes of batteries. The alternative would be (as has been done elsewhere) to have a smaller battery but increase the fleet of buses to allow for recharging time. Either way would make the use of battery-electric buses significantly more expensive than using

diesel vehicles (or even relatively expensive hybrids).

3. Technical, operational and business design criteria

Most studies to date on electric buses (and EVs in general) have concentrated on the technical design for low carbon vehicles with often superficial consideration of the institutional context and practices in which these technologies need to operate. The work behind the design of the Milton Keynes electric bus project has therefore sought a viable technical solution that reflects an understanding of:

1. The need to reduce battery size, so cutting the additional capital costs to a level that means the overall lifetime costs are comparable (or less) than for a diesel bus;
2. An 'Opportunity Charging' system that does not result in additional downtime, so requiring a larger fleet;
3. An 'Opportunity Charging' system that is sensitive to the operating culture and practices of the bus industry (allowing the bus to collect charge *en-route* without interrupting the operational timetable);
4. A business model that recognises, fairly allocates and manages the commercial risk involved.

Any approach that does not satisfactorily meet all these criteria will fail. The distinctiveness of the Milton Keynes project is that it represents an innovation diffusion process that places a technical solution in the context of financial viability managed by an appropriate new business model.

4. The design of the Milton Keynes electric bus service

The first part of the design is for the battery size to be reduced sufficiently so that the additional capital costs can be recouped by lower running costs (particularly fuel and maintenance) before the battery pack needs to be replaced.

Working from published data on fuel economy, for a medium sized electric bus covering around 80,000 kilometres a year, the use of electricity rather than diesel would save about £15,000 per annum. There will also be some reduced maintenance costs. Consequently to match diesel bus costs, any capital cost premium needs to be under about £80,000 assuming a battery life of 5 years¹. These generic cost structure figures illustrate the design challenge faced for the Milton Keynes trial which has sought a commercially viable approach. Furthermore, reducing battery size can only work if the design links to criteria (2) and (3). If a smaller battery is used, but more vehicles are needed then the cost will increase. The charging system also needs to work within the operating culture and practices of the bus industry.

Figure 4 presents the financial design challenge.

The numbers on the vertical scale of this diagram are indicative, but reflect generic industry data on bus capital and operating costs. Compared to a diesel bus, an electric bus (case A) costs about twice as much to buy or lease, but has lower running and maintenance costs and so should be able to match diesel bus costs over a five year period. However if the battery does not provide sufficient range and more vehicles are needed, then capital costs rise (case B), making the electric bus prohibitively expensive. The ideal would be to move to case C, using a smaller battery that is charged more frequently and so undercutting the overall cost compared to diesel.

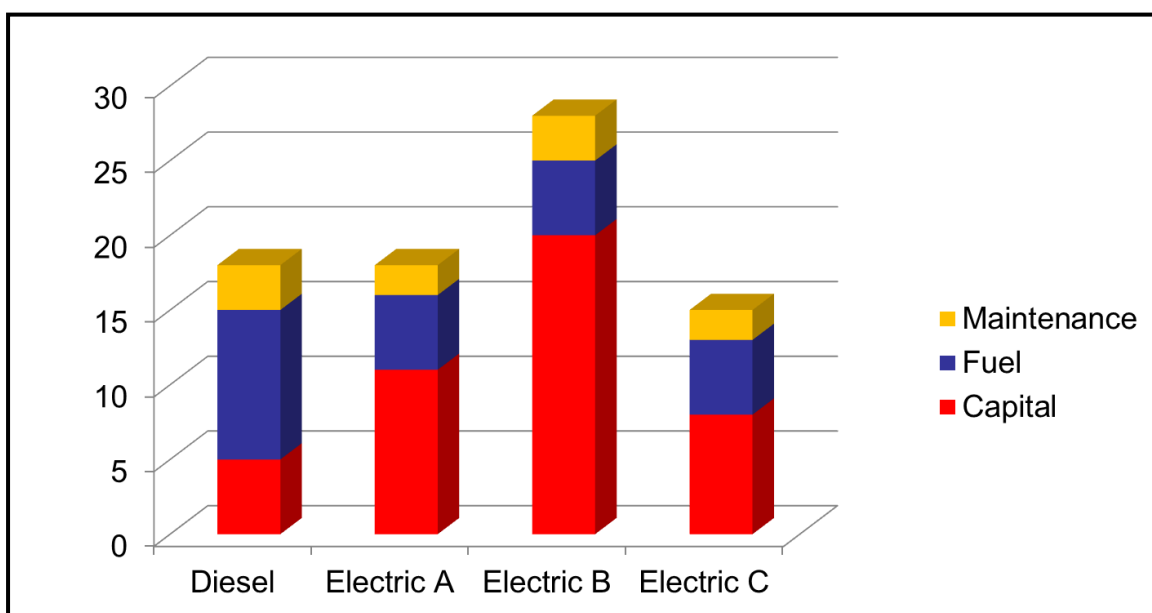


Figure 4. Indicative 5 year costs of electric buses

¹ Recent studies (like Element Energy, 2012) suggests an 8 year battery life. The shorter life assumed for the MK study reflects the high intensity of use envisaged.

Such a solution needs to represent an integrated financial and organisational approach. If the battery can be charged in the course of the working day and in a manner that is organisationally easy for staff, then the battery size can be reduced. However the solution should not interfere with the bus operator's timetable.

Bus timetables present windows for 'opportunity charging' as they incorporate turn-round times at the end of each route. This is to provide a robust timetable so that any unforeseen delay can be accommodated within a 5-10 minutes turn round time. If a bus arrives a bit late, it can then still leave on time. Most public transport systems have such 'turn-round' or 'recovery' times built into their timetables. Dwell time at bus stops (a minute or less) is not long enough to deliver sufficient electric charge into a vehicle, but the route-end, timetabled, dwell times offer a real potential for opportunity charging.

So an electric bus could start its day fully trickle-charged overnight and then be topped up at the route-ends during timetabled turn round times. Charging at route ends needs to achieve a high power transfer without requiring the driver to take special action. Expecting a driver to stop, get out, plug in the bus, wait, unplug and then drive off would eat into the short recharge time available, as well as add a clumsy procedure that may or may not be efficiently carried out. A key design criterion informed by this project's holistic approach required an automated procedure to quickly deliver large amounts of power. Inductive charging was chosen to achieve this.

Contactless inductive charging can deliver high power ratings (over 100KW) and has a high efficiency of transfer, in the range of 80-95% (Guho et al, 2012). There are also proven systems in operation. The charging unit is buried in the road surface and the charging process is automatically triggered when the electric bus stops over this. A plate under the bus lowers to produce a small gap across which the charge is transmitted (see Figure 5). This technology has a proven track record. It has been used successfully for the electric buses operating the city-centre 'Linea Star' route in Turin for the last eight years, using medium-sized (7.5 metre length) buses carrying 225,000 passengers per annum (Figure 6). Inductive charging has also been identified in other studies (e.g. Tzeng et al, 2005) as being a crucial component for any viable electric bus system design.

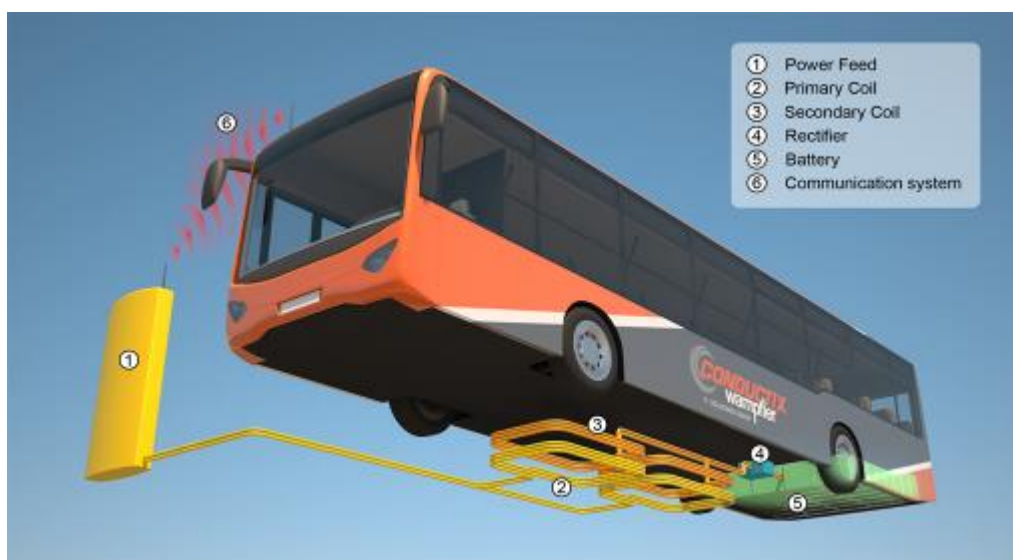


Figure 5. The inductive charging system Source: Conductix-Wampfler GmbH

In Milton Keynes, the German IPT-Technology (formerly Conductix-Wampfler) inductive charging system has been installed at two locations - one at each end of the route. As well as in Turin, this system has recently been trialled at s'Hertogenbosch in the Netherlands. Here larger (12 metre long) buses were used than in Turin (Eltis 2012).



Figure 6. (left) The Turin eBus charging on an inductive pad and (right) the electric bus charging pad installed at Wolverton in Milton Keynes.

Inductive systems are also being trialled in other locations. In his review of electric bus systems, Odell (2013) notes that, as well as the established IPT-Tech system, Bombardier are undertaking three different bus inductive charging trials in Europe. A six bus system began in Brunswick in Northern Germany in June 2013, with smaller schemes to follow in Mannheim and in Bruges in Belgium. Significantly, Bombardier see this system as applicable for its existing Light Rapid Transit business, with inductive charging to battery packs on trams replacing overhead catenaries. This sort of configuration also has the potential to deliver electrified Bus Rapid Transit. In the USA, HEVO have developed inductive charging systems for a variety of applications; although this does not include buses, it is proposed for electric delivery vehicles in New York.

5. The Milton Keynes route 7 trial

In Milton Keynes, the bus route that has been electrified is the No 7, which is a 24 kilometre long route running through very mixed operating territory (Figure 7). It starts in the Victorian streets of Wolverton and then runs along mixed roads to the CBD district of Central Milton Keynes and the central station, through new housing estates to Bletchley bus station. This route operates for 17 hours a day at a 15 minutes daytime frequency. The buses operate 90,000 kilometres a year per vehicle and the service carries 750,000 passengers a year. It is thus three times the size of the established Turin city centre scheme with a much heavier annual duty cycle for the buses.

Opportunity charging has been modelled for this route and indicates that a significant increase in vehicle range can be achieved, enabling the use of a smaller capacity battery pack with a substantially lower cost and mass. A 10 minute parking of the bus over a coil will replenish two-thirds of the energy consumed

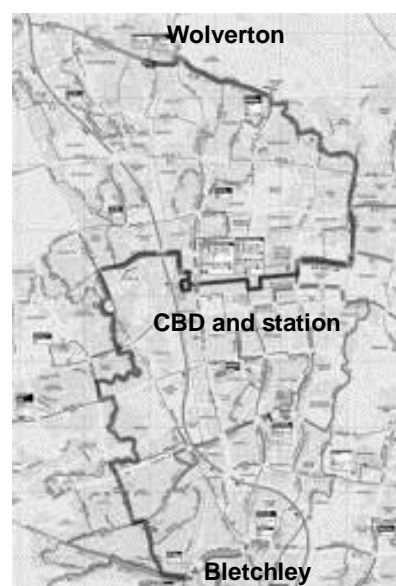


Figure 7. Milton Keynes bus route 7

on the bus's 24 kilometre route. The impact of the opportunity charging is shown in Figure 8. Whereas an overnight charge would only last for 8 hours, with opportunity charging an operational State of Charge (SoC) can be maintained for beyond the 18 hours needed for a bus to run all day. This would allow a bus to miss some recharging opportunities (e.g. when it was running late) and still operate a full schedule.

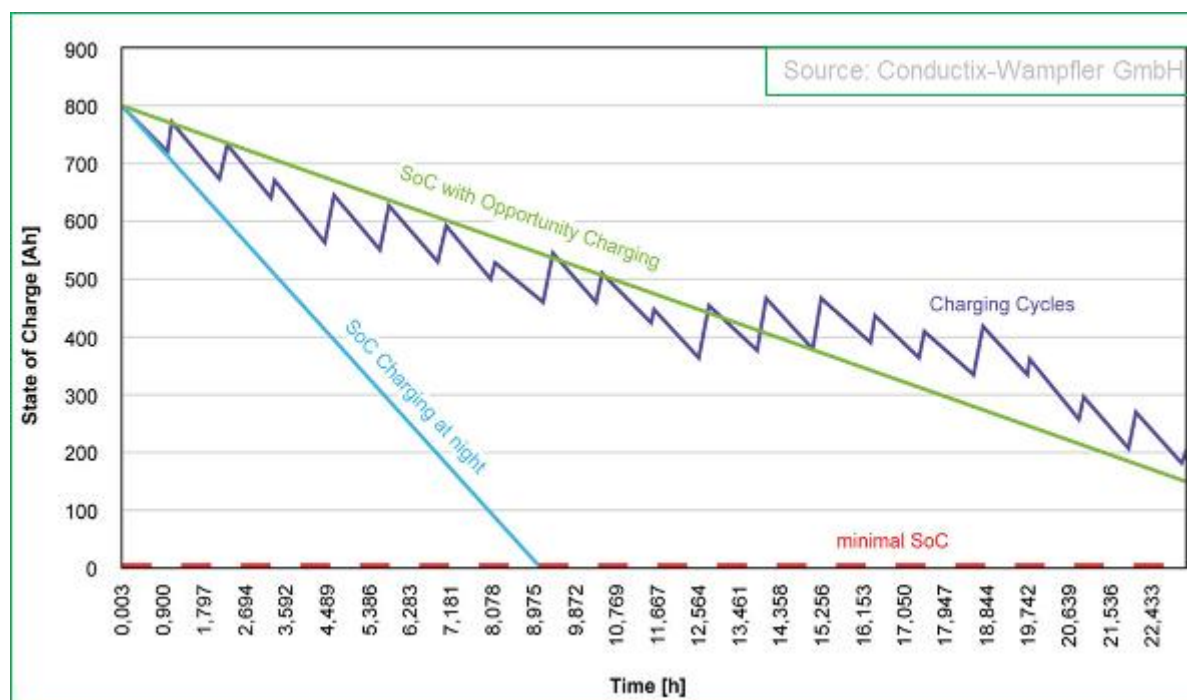


Figure 8. State of Charge modelled for the Milton Keynes electric bus.
Source: Conductix-Wampfler GmbH



Figure 9. An operational Milton Keynes electric bus charging from the inductive pad in Wolverton shown in figure 6.

Eight *Streetlite* electric buses have been purchased from the UK manufacturer Wrightbus (Figure 9). This is the company that makes the hybrid 'New Bus for London'. The new electric buses have replaced the seven diesel buses that previously operated on this route. The additional electric bus is partly a function of this being a small fleet; with a larger fleet a one-for-one replacement should be achievable. The charging points were installed in the summer of 2013. Running trials commenced in November 2013, ahead of public operations which began in January 2014.

With a 15 minutes frequency, only one charging pad is needed at each end of the route. Were more routes to be electrified or

the frequency increased, more charging pads would be needed.

Initially, public operations involved three electric buses together with diesel buses on the route, with the full fleet of eight electric buses in operation by April 2014. The initial experience is encouraging. Using the charging pads, the electric buses have operated as planned, with the batteries easily maintaining sufficient charge for the buses to operate a full working day. There have been some inevitable technical glitches that are to be expected at the start of a service trial of a new technical design, but these have been rectified.

The Milton Keynes trial will run to 2019 in order to collect detailed information on the technical and financial performance of the system. The long trial period is to ensure that battery life issues are addressed.

6. A business model for innovation

A crucial issue in innovation diffusion is that a new technology often requires a new risk management strategy to succeed. This, in turn, requires changes to the conventional business models which are usually based on the premise that risks are clearly understood and managed. The root of this premise lies in experience which, naturally, is lacking wherever innovation is being promoted. In the simplest of terms, it is insufficient to provide only subsidies; something more is needed in the way of risk management and organisational structure if innovative new approaches to transport are to be introduced successfully into mainstream operations.

The Milton Keynes demonstration project has been informed by an appreciation of this point. Specifically, a special-purpose 'Enabling Company' has been established which purchases the buses and chargers and then leases them to the operating company. This business model has several advantages:

- 1) It provides a purchaser who effectively underwrites the risk of developing a new bus and installing a novel charging infrastructure;
- 2) It leases the buses and allows use of the charging infrastructure to the bus operator at a pre-agreed price, thus shielding the operator from the technology risk;
- 3) It operates and maintains the charging infrastructure for the duration of the lease agreement;

The special-purpose Enabling Company is *electric Fleet Integrated Services Ltd*, (eFIS), a company that is owned in joint venture by Mitsui and Arup. The enabling company works mainly in the role of customer with all of the parties required to deliver the project including Milton Keynes Council, the bus operator Arriva, the bus manufacturer Wrightbus Ltd., the charger suppliers (IPT-Technology for the inductive devices and ChargeMaster for the overnight trickle chargers), the electricity network operator, Wester Power Distribution, and the electricity supplier, Scottish and Southern Electric.

Without this arrangement, there would be a real issue of business and technology risk. These are not the usual mix of partners who are normally needed to implement an ordinary new bus service. It is much more complex and the risks are not those normally faced. Whatever the potential benefits, nothing would have happened without the organisational structure that provides confidence for these partners to invest in the contribution they need to make. The enabling company provides a business model in which learning can occur and shields the bus operator from the initial risk of innovating.

If the electric bus is cheaper to operate than was originally estimated, the Enabling Company will make a profit. If the cost of the EV is more expensive in practice, the bus operator is shielded from the loss. This provides the confidence for all parties to participate in the project. If the commercial benefit can be demonstrated, then the partners will have established a way of working together that can be rolled out in a wider, private-enterprise, programme of bus electrification.

The use of this different business model has been crucial and is probably the most important aspect of the Milton Keynes electric bus project. It is the key to unlocking the benefits of a design configuration that can make electric buses commercially viable.

It is possible that this function could be undertaken in a different way within alternative regulatory structures. In a more regulated environment, a transport authority might take the enabling company's role and regulate access to the charging pads. However, an organisational structure with a capability for managing innovative situations is vital, and that is not always provided within the traditional culture and financial systems found in many city transport authorities.

6. Conclusions

This study not only provides an example of how to technically resolve the electric bus problem, but has addressed strategic issues about the organisational structures required to deliver innovative and sustainable public transport. The use of an intermediary enabling company links with existing research on the crucial role that such intermediary organisations play to address the technological, financial and infrastructure barriers to successful market diffusion. Stewart and Hyysalo (2008) note how such intermediaries operate along the supply-use axis bridging the user-developer innovation domains and connecting users (in this case the bus operator) with suppliers/producers.

The approach adopted in Milton Keynes raises important points for regulatory and innovation policy. There is government support for sustainable transport technologies, but these innovations require new institutional structures and business models as well. This need is well documented in innovation transition research and the Milton Keynes project has sought to develop such a structure.

The government plans to devote very large sums of money to the encouragement of ultra-low emission in the coming years. This provides a great opportunity to examine the performance of the enabling company described here and develop the concept so that the most effective business models can be deployed in future to accelerate innovation in public transport and encourage investments from the private sector.

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